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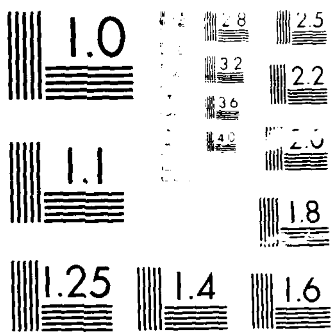
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Implicit Knowledge in the Identification of Environmental Sounds:

Causal Uncertainty and Stereotypy

James A. Ballas

Center for Behavioral and Cognitive Studies
Department of Psychology
George Mason University
Fairfax, VA 22030

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Two aspects of listeners' implicit knowledge about environmental sound were investigated: multiple causality and stereotypy. Several studies have demonstrated that the time required to identify an environmental is a function of the number of alternative causes, which defines causal uncertainty (CU). The procedure used to estimate causal uncertainty requires the collection and sorting of identification responses from a group of listeners. The number of unique responses is then used to calculate CU. Because the cognitive process implied by the role of CU assumes that listeners are informed about alternative causes, it was hypothesized that they might be able to directly estimate the number of alternative causes. In the first

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experiment, listeners were asked to estimate the number of alternative causes for a sound. These estimates correlated significantly with previous estimates of CU and sound identification times obtained from different listeners. In a second experiment listeners were given anchors for the number of possible causes of the sounds based upon the results of previous research. With anchors, the range of the estimates increased. These estimates correlated significantly with previous estimates of CU including estimates from the first experiment. Correlation of these estimates with identification time was significant but not different from the first experiment. Results from both experiments demonstrated the reliability of CU for specific sounds with changes in methods and listeners.

Previous work has shown that the time required to verify the category of an word is related to both the conjoint frequency of the category label and the word as well as the typicality of the word as a member of the category. The first effect has been found with sound identification in testing for the time taken to verify a cause of a sound; less probable causes take longer to verify. The second effect would require manipulation of the stereotypy of the sounds. In order to manipulate stereotypy in a later identification experiment, listeners were asked to describe their stereotypical notions of 20 sounds, both in words and by imitation of the sounds. Analysis revealed that the sounds varied in strength of stereotypy. For later research, the characteristics of stereotypical tokens of these sounds were obtained.

INTRODUCTION

The process of identifying a sound presented in isolation requires a cognitive consideration of alternative causes when these alternatives can produce similar acoustic effects. The uncertainty in such a situation is analogous to the indeterminate semantic reference of a homonym spoken in isolation. The time required to consider the alternatives is a function of the number of alternatives (Ballas, Sliwinski, & Harding, 1986) which can be estimated by asking for identification responses from a group of listeners and counting the number of different responses. Estimates of the number of alternative causes are reliable for different groups of listeners and for different tokens of common sounds (Ballas, Dick & Groshek, 1987; Ballas & Howard, 1987). This reliability suggests that listeners have implicit knowledge about the domain of alternative causes. However, a method other than that used by Ballas and his colleagues must be used to assess this implicit knowledge.

The estimation of causal uncertainty (CU) takes multiple responses from individuals and tallies the frequency of each response within the group. All responses are given equal weight. This method is similar to procedures that are used in verbal research. The method of counting the number of alternative causes is similar to the production measures used to quantify aspects of verbal materials (Cofer, 1971). For example, Noble (1952) estimated meaningfulness of consonant-vowel-consonants (CVCs) by calculating the average number of association responses produced in 60 s by individual listeners. This

multiple-response procedure is similar to the single-response procedure in which only one or the first response of a subject is used (Battig & Montague, 1969). Data in the latter paradigm are tallied for the group of listeners. Group data are similarly obtained in estimating CU. When used to estimate the relative size of categories, both procedures give comparable results (McEvoy & Nelson, 1982). However, when used to estimate population values, the proportions obtained with estimation methods may be biased (MacFae, 1971) and a multiple response procedure is one means of compensating for this bias (Ballas & Sliwinski, 1986). Neither procedure is adequate to assess implicit knowledge. The single-response procedure produces only a single cause from each listener even though knowledge of multiple causes may be present. The multiple response procedure would reflect implicit knowledge, but when it was available as an option, few listeners used it in the studies by Ballas and his colleagues.

Alternatives to the production method are available to assess the listener's implicit knowledge about sound causality. One alternative is the rating scale which has been used to assess verbal materials on category size (Battig & Montague, 1969), semantic distance between words (Rips, Shoben, & Smith, 1973), goodness of example (Rosch, 1975), meaningfulness and association value (Noble, Stockwell, & Pryor, 1957), concreteness and specificity (Spreen & Schultz, 1966). Measures on similar dimensions obtained by different methods (e.g., rating scales and production methods) are significantly correlated (Cofer, 1971; Mervis, Catlin, & Rosch, 1976). The correspondence of multi-method estimates in verbal research may also occur in estimating

CU. If estimates of CU are reliable across methods, this would support the use of CU as a measure of sound identifiability given its reliability across listeners, sorters, and tokens of particular sounds.

As an alternative to the estimation of CU, the rating scale method must be sensitive to the number of alternative causes. The actual number of alternative causes could in principle be counted if sound equivalence in the perceptual domain could be determined. However, the signal sampling and analysis would be formidable. This is why the listener's knowledge of sound is utilized to define the domain of alternative causes. Certain work in verbal research is particularly relevant to this substitution of listener's judgments for measurements that cannot be made. Howes (1954) found that judgments of word frequency were correlated with actual counts ($r = .80$). Thus judgments can be substituted for counts in certain instances. However, the judgments that Howes required of his participants were of a different sort than the judgments needed for CU. The judgments in Howes' study could be made by accessing the encoded occurrence of an item, using the item itself as the retrieval cue. Judgments of the number of alternative causes cannot be made on the same basis because these judgments must be based upon the size of a category, not the occurrence frequency of an item. Furthermore, the category would be defined by common acoustic properties shared by dissimilar causal events. Thus the relationship between the causal magnitude judgment and the retrieval cue (i.e., a sound) is complex, requiring assimilation in one domain (acoustics) and differentiation in another

domain (cause).

There are several possible scenarios for this process. The size of the category could be judged if: 1) it were coded with each member of the category; 2) it were obtained by searching the category and tallying the number of members; or 3) presentation of a specific sound activates memory for an acoustic category (i.e., a generic sound) which includes information about the number of causes for the sound. Research by Brooks (1985) with verbal materials would cast doubt on the first alternative. Brooks studied the estimation of category size and found that size is not encoded with the instances of the category. Judgments of category size were related to the occurrence frequency of all items within a category even though the categories were not presented with the instances. Category size judgments were not related to the occurrence frequency of *specific* items in the category suggesting that the occurrence frequency was encoded with the category, not with the instance.

Response time differences in identifying a sound and in confirming possible causes of a sound would suggest the second alternative (Ballas & Sliwinski, 1986). Thus it would seem possible to ask listeners to directly estimate the number of alternative causes under the assumption that such a judgment would require either a search of the domain of alternative causes or retrieval of category size information encoded with acoustic memory for the sound. This last possibility assumes that the presentation of a sound activates an acoustic category and that response time differences are due to memory activation time differences.

EXPERIMENT 1

Direct estimation of causal magnitude raises several issues which need to be investigated. The first issue is whether the two methods produce similar estimates. Other issues involve procedural matters. It is known that procedural design influences the variability and magnitude of scales derived through the direct methods (Baird & Noma, 1978). Such may be the case in the scaling of causal magnitude. Empirical evidence must be examined to assess effects of several procedural alternatives including the use of anchors, the position of the anchors with respect to the stimuli, and the phrasing of instructions. The following experiment was designed to elicit numerical estimates directly without prompting the listeners with anchors.

Method

Participants. Twenty undergraduate students participated on a volunteer basis and were paid for their participation. Their ages ranged from 18 to 21. Twelve were females and eight were males. None reported any hearing disorders and most had received musical training.

Stimuli. The set of stimuli included six practice sounds and 41 test sounds obtained from seven high-fidelity sound effects records. This was the same set of sounds used in previous experiments (Ballas & Sliwinski, 1986). The sounds were digitized at 20 kHz for 1.5 s through a low pass filter set at 10 kHz. A .5 s section of the sample was selected from each stimuli, produced through a digital-to-analog

converter (DAC) at 20 kHz through a low-pass filter set at 10 kHz. The practice sounds consist of various animal sounds and a baby crying. The test sounds were selected to represent a wide variety of environmental sounds and to pose both easy and difficult recognition problems within a reasonable uncertainty range.

Procedure. Listeners were seated in a sound attenuating booth and received instructions and responded using a computer which generated the sounds and controlled the trial protocol. The sounds were in random order. Each sound was presented as often as each listener wished. After hearing the sound, the listeners entered a number to indicate the number of potential causes of the sound and verified this number. No constraints were placed on the size of the number that could be entered.

Upon completion of the experiment, the listeners were asked to complete a questionnaire which solicited information about the listeners' familiarity with the events which had produced the sound. Familiarity was rated on a six-point rating scale. The questionnaire also solicited information about the person's hearing, musical training, and several other variables of interest.

Results and Discussion

Geometric mean estimates of the number of possible causes, averaged across listeners, ranged from 1.04 for both the sound of a telephone ringing and the sound of a riverboat whistle to 2.66 for the sound of a car backfiring. The upper end of this range is much less than the number of categories used by the sorters in the Ballas and

Sliwinski study (1986). The largest number of categories used by the three sorters was 28, 31, and 38 respectively. Thus this method of direct estimation results in truncated estimates of the number of causes. Even with this truncation, Spearman rank-order correlations between the direct estimates and the three estimates of CU reported by Ballas and Sliwinski (1986) for the same sounds were significant (r = .67, .75, .69, p < .0001, for the three sorters used by Ballas & Sliwinski to organize the response data into categories of similar identification responses). The rank-order correlation of the direct estimates, with the response time that listeners in the first Ballas and Sliwinski experiment took to identify the sound, was significant (r = .77, p < .001). This correlation was less than the corresponding correlations of response time with the three estimates of CU (r = .81, .87, .82). Only the greatest difference (.87 - .77) is significant (t = 2.02, p = .05 on a test of dependent correlations). Thus the direct estimates correlate with the performance measure of identification response time about as well as CU.

Judgments of causal magnitude could be related (and perhaps dependent upon) other aspects of the stimulus. For example, more exposure to the sound might be related to larger estimates of causal magnitude because greater exposure would include experience with more causes of a different nature. If so, then individuals who made larger estimates would be more familiar with specific events that could cause the sound. To illustrate, if prior exposure is the determining factor in the estimate of the number of alternative causes to sound _X_, which has as potential causes events _A_, _B_, and _C_, then listeners who gave

larger estimates for sound X would be more familiar with each of the events A, B, and C. A particular listener might only be familiar with events A and B, but in the aggregate, the listeners with who produced larger estimates would be more familiar with the causes if prior exposure is the determining factor.

In order to assess this possibility, ratings of familarity with reasonable causes of the sound (in fact, the actual cause of each sound) were compared with causal magnitude estimates. Product moment correlations were used to minimize Type II error which would increase with the attenuated rank-order correlations. For the 41 sounds, only two correlations were significant ($p < .05$) which is precisely the number that would be expected due to Type I error. Twenty of the correlations were negative and 21 positive, further evidence of no relationship between familarity and causal estimates. Mean familarity ratings ranged from 1.11 to 4.72 on the six-point scale. Standard deviations ranged from .32 to 1.81.

EXPERIMENT 2

The reduced relationship with identification response time might have been due to the restricted range of the estimates. Range restriction will reduce correlations and can also affect the size of the exponent found in the direct scaling of sensory magnitude (Baird & Noma, 1978). To assess the effect of an expanded response range on causal magnitude estimates, a second experiment was conducted in which

the listeners were advised of the number of potential causes. This procedure gave the listeners an upper anchor which they could use to make their judgments. The effect of an anchor on stimulus judgments depends upon the specific experimental details (Baird & Noma, 1978). The only change made in the following experiment from the design of Experiment 1 was to provide an anchor for the upper end of the response range. Thus the stimulus range was held constant. However, since an upper anchor was provided, all the stimuli would be judged to be less than or equal to the anchor provided. These conditions are comparable to a direct scaling experiment in which the modulus of the standard is large and all the stimuli are judged to be fractions of the standard. These conditions produce larger power exponents which means that the response range is being expanded. A similar effect would be expected here.

Because the purpose of these studies is to investigate the listener's natural knowledge about sound causation, the listeners in this experiment were not told which of the sounds prompted the largest number of alternative causes and were in a sense not provided with a standard stimulus as is done in a scaling study. Providing a stimulus as a standard would give the listeners information about a particular sound and perhaps bias their pre-experimental knowledge about sound causation. Informing them about the maximum number of causes that previous research had determined about these sounds would allow them to adjust their numeric response scale to a range consistent with previous research. This would reduce the effects of magnitude range in a comparison between results of different procedures used to

estimate causal magnitude.

Method

Participants. Sixteen undergraduate students were recruited and paid for participating in the study. Their ages ranged from 18 to 24. Six were female and 10 were male. None reported having a hearing loss and 9 had formal musical training.

Stimuli. The set of sounds was identical to the sounds used in the first experiment and in the studies reported by Ballas and Sliwinski (1986).

Procedure. The experiment was identical in all respects to the first experiment with one exception. The listeners were told that in previous research it had been found that the number of potential causes of the sounds ranged from one cause for some sounds to as many as 35 for other sounds. This range was presented to the listeners in the instructions and was presented as part of the prompt on the computer screen requesting the entry of an estimate of the number of causes. The value for the upper anchor represented the maximum number of categories used by the sorters in the Ballas and Sliwinski study.

Results and Discussion

Geometric mean estimates ranged from 1.57 for the sound of a bugle charge to 10.49 for the sound of an axe chop. The upper end of the range increased substantially with instructions about the range of causal uncertainty found in prior research. The rank-order correlation of these estimates with identification response time was

significant ($r = .65$, $p < .0001$). This correlation was less than the corresponding correlation in the first experiment but the difference was not significant ($t = 1.69$, $p = .10$). Although the range was increased, the relationship with a behavior measure of identification time was not changed. The rank order correlations of these expanded extimates correlated significantly with the estimates obtained by Ballas & Sliwinski using the sorting procedure ($r = .58, .70, .62$, $p < .0001$ for correlations with the estimates from the three sorters respectively) indicating as in Experiment 1 that estimates of uncertainty are reliable with different methods.

Product moment correlations between familarity and causal estimates were computed as in Experiment 1. Six of the 41 correlations were significant ($p < .05$) and 11 of these were positive. Twenty-seven of the correlations were positive. The expanded range of the estimates increased the size of these correlations, but still the effect of familarity is minor.

Rank order correlations of the geometric mean estimates from the two experiments were significant ($r = .76$, $p < .001$). The two experiments involved different listeners and a revised procedure providing anchors in Experiment 2. Even with these changes, reliable estimates were still obtained for the common set of sounds. These two experiments demonstrated that direct estimates of causal magnitude are closely related to calculated CU and identification response time and imply that listeners have implicit knowledge about the relative magnitude of alternative causes. This knowledge is shared across listeners for the kinds of common sounds studied.

EXPERIMENT 3

The results of the first two experiments confirm that listeners have knowledge about the number of alternatives and together with previous studies support the view that the recognition of a particular sound may involve a cognitive process wherein people consider alternative causes and that the time course of this process is related to the number of alternative causes. This finding is analogous to the established fact that the time required to decide on the class membership of a word increases with the size of the predicate concept (Collins & Quillian, 1969). For example, the question,"Is a canary a bird?" takes less time to answer than the question,"Is a canary an animal?" However, predicate concept size is not the only factor affecting response time. Later work showed that the typicality of the category instance, i.e., what one is trying to classify, also influenced the speed of deciding on class membership (Rosch, 1975).

An analogous typicality effect might occur in the case of sound identification. This issue arose in a recent experiment. The study used a priming paradigm in which listeners were presented with causes of sounds visually (on a computer screen), and then asked to judge whether or not sounds presented to them through headphones could have resulted from the cause described in the prime. These primes were obtained from a previous experiment in which participants had listened to the same set of sounds and provided possible causes for them. A high frequency and a low frequency prime were used for each sound, the high frequency prime being a cause that was suggested by many

listeners and the low frequency prime being a cause that was rarely suggested. Results showed that it took longer to respond affirmatively after having seen a low frequency prime than when one had seen a high frequency prime.

This suggests that there may be a memory network search or spread of activation going on in sound recognition, wherein causes which are more frequently associated with a particular sound have a smaller functional distance from that cause, and thus a faster reaction time, than do those causes which are more remotely associated. A spreading activation model has been suggested for perception of musical chords by Bharucha and Stoeckig (1986) and reaction time data have supported his proposal. However, there may be a confound between the probability of the prime and the suggestion from listeners that sometimes the sound actually presented differed from expectations formed upon reading the prime. This suggestion led us to wonder whether there are subjective prototypes or ideal typical examples of 'what a sound sounds like' and the following experiment was designed to address this question.

Our purpose in conducting this type of experiment was to reveal any specific instances in which one version of a sound is more typical than another version. In order to avoid stimulus sampling bias, we chose not to have listeners rate the typicality of a set of instances of a sound, a procedure used in rating the typicality of words (Rosch, 1975). Instead, we chose to solicit descriptions of the sounds. This procedure presented difficulties of a different sort. Research by Wright (1971) demonstrated that descriptions of complex sounds (i.e.,

sounds that vary in several dimensions) are inconsistent across listeners. Even the use of onomatopoeic descriptions was inconsistent. Therefore, there was some question as to whether the written descriptions alone would produce reliable results. As a check on the written descriptions, we asked our listeners to vocally imitate the sounds. This alternative was expected to produce cognitive stereotypes of the sounds, based upon the results of Lass et al. (1984) who found that imitations of animal sounds were more accurately identified than actual recordings. They suggested that the imitation of the sound matched perceptual expectations of the sound. Thus imitation is a reasonable procedure to use in soliciting perceptual knowledge such as sound stereotypy.

Method

Participants. Twenty undergraduate students volunteered for this study and were paid five dollars each for their participation. The ages of the listeners ranged from 19 to 22 and of the twenty listeners, 11 were female and 9 were male. None of the participants reported any hearing disorders and a little more than half had received some formal training in music and/or voice.

Stimuli. The listeners were presented with a list of twenty events and were asked to vocally imitate the sounds that are produced by those events. Later they were asked to provide written descriptions of those sounds. Thus, the stimuli were the twenty events. The events chosen for the list were selected from sound effects records and from the event list employed in research conducted

by Ballas and Sliwinski (1986). These events were chosen on the basis of the identifiability of the sounds they produce. Events were selected from both the high and low identifiability ends of the scale and some were then eliminated because of the poor results they produced in a preceding pilot study. The three types of sounds used were animal, signaling and general environmental (see Table 1).

Apparatus. Two sound attenuating booths were employed. The listeners sat in one booth which contained a microphone that was wired to a tape recorder in the other booth, in which the experimenter was positioned. Communication between the listeners and the experimenter was carried on through a two-way intercom system.

Procedure. The listeners first were asked to vocally produce a number of sounds read to them individually by the experimenter. A random number generator program was employed to assign the order in which the twenty sounds were produced by each participant. Each participant was allowed as much time as needed to practice. In order to assure the listeners of privacy during practice and recording of the sounds, they were informed, prior to the beginning of the experiment, that the experimenter could not hear them produce the sounds but that their versions of the sounds were directly recorded onto the respective tapes. After having completed this phase of the experiment the participants were asked to complete written descriptions of the twenty sounds they had previously produced vocally. They were asked to include in these descriptions the auditory sensations and temporal properties of the sounds. Following the completion of this phase participants were then asked to fill out

a biographical questionnaire consisting of the following areas of inquiry: name, sex, age, year in school, possible hearing disorders, and extent of formal training in music and/or voice, if any. Also included on this questionnaire was a list of the sounds involved in the experiment and a rating scale with which the listeners were asked to rate the degree to which they were familiar with each of the sounds. The scale ranged from 1 to 6 with 1 designating familiar and 6 representing unfamiliar.

The analytic procedure used on the data gathered in phases one and two was based on a procedure used in a pilot study that was run prior to this experiment. Initially, the vocal productions of the sounds were analyzed separately from the written descriptions. Two research assistants individually categorized the vocal productions of the sounds based on the number of components and the auditory sensations of each version. The written descriptions were then sorted into categories using the same criteria. The sorters' results were then compared separately for each phase and the similarities were noted as possible stereotyped conceptions of the sounds. Finally, the sorters created a joint vocal/written categorization matrix to compare the vocal imitations to the written descriptions and find similarities and differences in stereotyped concepts in the two modalities. The categories for the matrix were determined by the sorters as they reviewed together both the vocal imitations and written descriptions of the sounds.

Results and Discussion

Vocal imitations and written descriptions of the 20 sounds ranged in terms of stereotypy from those which were similar for almost all listeners to those which were different. These results are summarized in Table 2, which includes notation of the most common vocal imitation in the International Phonetic Alphabet, a summary of the most common written description, the frequencies of these responses, and the familiarity rating for the event. In addition, the joint occurrence frequencies of the most common vocal imitation and the most common written description are listed. This last statistic describes the coincidence of the vocal and written modes of description. This statistic is a defensible indicator of stereotypy because it reveals cognitive knowledge of a sound that is consistent across different modes of expression. Thus it is an indicator of inter- and intra-listener consistency.

In general, the signaling sounds were the most stereotypical among the set of sounds examined. The two sounds with the largest joint frequency were signalling sounds. The church bell, factory whistle, and car horn had lower levels, but the car horn levels were due to a bimodal division of responses between a "honk" and a "beep". Combining these two would put this sound within the top five sounds in stereotypy level.

The average familiarity rating for each sound (data from the biographical questionnaires) was correlated with vocal, written, and joint response frequencies in order to evaluate the role of familarity with the event in the development of a stereotype. These correlations

were not significant which means that factors other than familarity as assessed by the questionnaire determine the development of a stereotype. Several sounds in particular violate a possible relationship between familarity and stereotypy and familarity. The earthquake had a moderate typicality level that was inconsistent with the expected unfamiliarity of the listeners with this event. On the other hand, the sounds of a footstep and water drip although very familiar to the listeners were not described in a stereotypical manner. This result is particularly surprising for the water drip, which is accurately identified in different versions (Ballas & Howard, 1987; Ballas, Sliwinski, & Harding, 1986). This suggests that neither stereotypy nor familarity is the dominant factor in the identifiability of a sound, and is consistent with the view that causal uncertainty is the dominant factor.

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Table 1

Events used to solicit stereotypical descriptions

Type of event	Event
Animal	Gorilla making vocal noises
	Ducks vocalizing
	Wolves vocalizing
	Lion making vocal noises
Signaling	Doorbell being rung
	Factory whistle being sounded
	Telephone ringing
	Church bell being rung
	Car horn being blown
General Environmental	Stapler being pressed
	Arrow being released from its bow
	Helicopter starting up
	Whip being thrown and drawn back
	Car backfiring
	Footsteps
	Light switch being pulled
	Air rising in a water cooler
	Earthquake tremor
	Rifle being shot outdoors
	Water dripping

Table 2

Vocal imitations and written descriptions of sounds of events

Event	Vocal Mode	N	Written Mode	N	Joint N	Fam Rating
doorbell	|diŋ dɔŋ|	19	ding-dong	19	19	1 0
telephone	|briŋ|, |driŋ|	18	bring, dring	16	15	1.05
ducks	|kʌæk|	16	quack	16	14	2.0
wolves	|ao:|	14	ah-ooo	15	13	2 3
earthquake	|r.|	13	low rumble	13	12	4 95
light switch	|tʃk tʃk|	11	click-click	11	10	1 55
church bell	|bəŋ:|	12	low resonant gong	15	10	1 6
rifle outdoors	|pko:|	13	crack with echo	12	9	2 7
air rising in water cooler	|blup|	11	bloop-bloop	9	9	2 9
whip crack	|whtʃ|	10	whir-crack	15	8	2 9
gorilla	|uuu|	11	ouh	8	7	3 75
factory whistle	|tut|	11	hollow toot	8	6	3 0
car horn	|bip| |hɔnk|	6 12	beep loud nasal sound	6 9	5 8	1.3
lion	|rowr| |gr:|	9 9	roaring growling	9 9	5 6	1 3
stapler	|tʃk tʃk|	8	clicking	12	6	1 7
car backfire	|pku|	7	sharp bang with echo	14	5	2 65
arrow shot	|ft|	6	whssh, swoosh	7	2	3 7
footstep	tongue click	7	tap-tap	6	2	1 35
helicopter	|tʃ tʃ tʃ|	4	chopping sound	5	1	2 0
water drip	tongue click	5	plop-plop	5	1	1 4

OSD

Dr. Earl Alluisi
Office of the Deputy Under Secretary
of Defense
OUSDRE (E&LS)
Pentagon, Room 3D129
Washington, D.C. 20301

Department of the Navy

Aerospace Psychology Department
Naval Aerospace Medical Research Lab
Pensacola, FL 32508

Aircrew Systems Branch
Systems Engineering Test
Directorate
U.S. Naval Test Center
Patuxent River, MD 20670

Mr. Phillip Andrews
Naval Sea Systems Command
NAVSEA 61R2
Washington, D.C. 20362

Mr. Norm Beck
Combat Control Systems Department
Code 221
Naval Underwater Systems Center
Newport, RI 02840

LCDR R. Carter
Office of Chief on Naval Operations
OP-933D3
Washington, D.C. 20350

Dr L. Chmura
Computer Sciences & Systems
Code 5592
Naval Research Laboratory
Washington, D.C. 20350

Dr. Stanley Collyer
Office of Naval Technology
Code 222
800 North Quincy Street
Arlington, VA 22217-5000

Commander
Naval Air Systems Command
Crew Station Design
NAVAIR 5313
Washington, D.C. 20361

Dean of the Academic Departments
U.S. Naval Academy
Annapolis, MD 21402

Director
Technical Information Division
Code 2627
Naval Research Laboratory
Washington, D.C. 20375-5000

Dr. Raymond M. Fitzgerald
Code 1125A[illegible]
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217-5000

Dr. Robert A. Fleming
Human Factors Support Group
Naval Personnel Research &
Development Center
1411 South Fern Street
Arlington, VA 22202-2896

Dr. Eugene E. Gloye
ONR Detachment
1030 East Green Street
Pasadena, CA 91106-2485

Mr. Jeff Grossman
Human Factors Laboratory, Code 7
Navy Personnel R&D Center
San Diego, CA 92152-6800

Mr. Paul Heckman
Naval Ocean Systems Center
San Diego, CA 92152

Human Factors Branch
Code 3152
Naval Weapons Center
China Lake, CA 93555

Human Factors Department
Code N-71
Naval Training Systems Center
Orlando, FL 32813

Human Factors Engineering
Code 441
Naval Ocean Systems Center
San Diego, CA 92152

CDR. Thomas Jones
Code 125
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Mr. Todd Jones
Naval Air Systems Command
Code APC-205G
Washington, DC 20361-1205

Dr. Michael Letsky
Office of the Chief of Naval
Operations (OP-01B7)
Washington, D.C. 20350

LT. Dennis McBride
Human Factors Branch
Pacific Missle Test Center
Point Mugu, CA 93042

LCDR Thomas Mitchell
Code 55
Naval Postgraduate School
Monterey, CA 93940

Dr. George Moeller
Human Factors Engineering Branch
Submarine Medical Research Lab.
Naval Submarine Base
Groton, CT 06340-5900

CAPT W. Moroney
Naval Air Development Center
Code 602
Warminster, PA 18974

Dr. A. F. Norcio
Computer Sciences & Systems
Code 5592
Naval Research Laboratory
Washington, D.C. 20375-5000

Office of Naval Research
Code 1142PS
800 North Quincy Street
Arlington, VA 22217-5000 (3 copies)

Dr. Gary Poock
Operations Research Department
Naval Postgraduate School
Monterey, CA 93940

Dr. Randall P. Schumaker
NRL A. I. Center
Code 7510
Naval Research Laboratory
Washington, D.C. 20375-5000

LCDR T. Singer
Human Factors Engineering Divis
Naval Air Development Center
Warminster, PA 18974

Dr. A.L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Washington, D.C. 20380

Mr. James Smith
Code 125
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Special Assistant for Marine
Corps Matters
Code COMC
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

Mr. H. Talkington
Engineering & Computer Science
Code 09
Naval Ocean Systems Center
San Diego, CA 92152

Dr Jerry Tobias
Auditory Research Branch
Submarine Medical Research Lab
Naval Submarine Base
Groton, CT 06340

Department of the Army

Director, Organizations and Sys
Research Laboratory
U.S. Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333-5600

el Drillings
earch Office
:arch Institute
enhower Avenue
ia, VA 22333-5600

ar M. Johnson
al Director
my Pesearch Institute
lria, VA 22333-5600

cal Director
Army Human Engineering
itory
een Proving Ground, MD 21005

tment of the Air Force

Charles Bates, Director
n Engineering Division
AMRL/HES
ght-Patterson AFB, OH 45433

Kenneth R. Boff
AMRL/HE
ight-Patterson AFB, OH 45433

. J. Tangney
fe Sciences Directorate, AFSOR
olling AFB, Bldg 410
ashington, D.C. 20032-6448

Other Government Agencies

Defense Technical Information
Center
Cameron Station, Bldg. 5
Alexandria, VA 22314 (2 copies)

Dr. Clinton Kelly
Defense Advanced Research
Projects Agency
1400 Wilson Blvd.
Arlington, VA 22209

Dr. Alan Leshner
Division of Behavioral and
Neural Sciences
National Science Foundation
1800 G. Street, N.W.
Washington, D.C. 20550

Dr. M. C. Montemerlo
Information Sciences &
Human Factors Code RC
NASA HQS
Washington, D.C. 20546

OTHER ORGANIZATIONS

Dr. James H. Howard, Jr.
Department of Psychology
Catholic University
Washington, D.C. 20064

Dr. Jesse Orlansky
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22311

Dr. Richard Pew
Bolt Beranek & Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

Dr. James A. Simmons
Department of Psychology
Brown University
Providence, RI 02912

Dr. H. P. Van Cott
NAS-National Research Council
Committee on Human Factors
2101 Constitution Ave., N.W.
Washington, D.C. 20418

Dr. Milton Whitcomb
NAS-National Research Council
CHA BA
2101 Constitution Ave., N.W.
Washington, D.C. 20418

Dr. William A. Yost
Parmly Hearing Institute
Loyola University
6525 North Sheridan Road
Chicago, IL 60626

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